N77-33055

ANALYSIS OF LIQUID-PROPELLANT ROCKET ENGINES DESIGNED BY F. A. TSANDER+

Leonid S. Dushkin and Yevgeny K. Moshkin (USSR)++

One of the characteristics of the scientific and technical activity of F. A. Tsander in the area of the development of rocket technology and astronautics was his great activity and productivity in formulating and conducting engineering work on the practical utilization of the principles of reactive motion. He was moved by a deep conviction of the possibility of accomplishing manned space flight in the immediate future within the existing level of science and technology. A prominent scientist in researching a wide circle of problems in the theory of reactive motion and interplanetary flight, Tsander devoted a significant part of his efforts to practical engineering and design problems directed toward producing experimental liquid-propellent rocket engines suitable for use in flying vehicles of various types.

An extensive list of topics for practical investigation and development, formulated by Tsander, was devoted mainly to the energetics of reaction engine power plants. It included investigations in the application of metals and supplementary fuel in liquid-propellent rocket engines (LPRE), the successful application of new thermodynamic cycles, the development of designs and utilization of operating processes in LPRE, and the search for ways to increase the efficiencies of the assembly and the specific impulse of the engine. First among these tasks was the problem of producing reliable samples of LPRE. Tsander gave great consideration to the practical development of LPREs, and considered it basic to the successful development of rocket technology and the creation of the foundations of astronautics. At the same time he clearly recognized the great complexity and difficulties in solving this problem.

The high scientific and engineering erudition of Tsander in the area of aviation engine design and related technologies, his insight into choices for developing rocket

+Presented at the Sixth History Symposium of the International Academy of Astronautics, Vienna, Austria, October 1972.

++Dushkin specialized in rocket engine design and development during the 1930s and 1940s in GIRD, RNII, and other scientific institutes. Moshkin, a specialist in liquid rocket engine injector design, is an engineer presently affiliated with the Ministry of Aviation Industry.

98

PAGE INTENTIONALLY BLANK

technology, and his knowledge of the state and level of developments in various areas of science in the USSR and abroad, permitted him to develop his own original program of work—a program designed for successful completion with a minimum of effort and expense, and within the limited possibilities of obtaining material and technological assistance. This program provided for the development of methods for engineering calculation of engine processes and the choice of the optimum parameters for the operation of its assemblies; the development of laboratory models of LPRE and experimental tests to verify theoretical calculations, and the selection of rational shapes and dimensions of the structural elements; the construction and finishing of engines, mounting them in test vehicles, and carrying out flight tests.

F. A. Tsander successfully realized this program between 1928 and 1933. He performed the first and second stages in individual order without interrupting his main activity in the aviation industry. He performed the third stage of work with a small group of young specialists in the experimental-design organization, the Group for Study of Jet Propulsion (GIRD), created in Moscow during the fall of 1931 and headed by S.P. Korolev.

A number of studies in the history of the development of rocket technology and astronautics consider the practical works of F.A. Tsander on LPRE as important stages in the development of Soviet rocket technology, but his works are often dealt with schematically, without a detailed analysis of their directionality, originality, and maturity of creative solutions, or their scientific, technical, and practical value. An attempt is made in this report to deal with the practical works of Tsander on LPRE in more detail, on the basis of preserved archive materials, and also on the basis of personal recollections of the authors of the report, since they were fortunate to be his students and work under his direction in GIRD on LPRE during 1932-1933.

The development of methods for calculating the engineering performance of LPREs began to occupy Tsander at the beginning of the 1920s. His basic idea involved the construction of an interplanetary craft combining the features of an airplane with a liquid-propellent rocket, in which certain metallic parts of the airplane and rocket structure are used as supplementary fuel after they are no longer needed, when the craft had passed out of the atmosphere.

The choice of propellents was a fundamental problem. From the very beginning, Tsander dwelt on his choice of cryogenic propellents as having the highest energy potential—liquid oxygen as the oxidizer and liquid hydrogen as the fuel. Later he regarded liquid hydrogen as promising the greatest potential, but for the initial stage of the work he chose the more readily available aviation gasoline as the fuel for LPRE. The orientation toward aviation gasoline as the fuel in an oxygen LPRE, instead of liquid hydrogen, resulted not only from the difficulties in producing and handling liquid hydrogen during this time, but also because Tsander, in developing his ideas about a combined airplane and rocket in an interplanetary craft, wanted to use a single fuel for both engines onboard the craft.+

F. A. Tsander provided for the possi[illegible]ity of [illegible]ng liquid oxygen not only in pure form, but also in the form of a mixture of liquid air with various values of oxygen concentration, that permitted not only performing work in stages on the LPRE, but also improved the performance of the ordinary aviation piston engines.

An important theoretical result of Tsander's work was the development of an engineering method for propellant calculations of oxygen-propellent rocket engines that, for practical purposes, determined the basic parameters of the engine and the structural elements. Consideration of the effect of dissociation of gases, precise determination of the heat transfer coefficients of the gases to the chamber wall and of the wall to the surrounding medium, and the calculation of the volume and shape of the combustion chamber, were characteristics of this method. This method produced data close to the actual values, and established Tsanders calculations in LPRE in the class of mature and original scientific and technical solutions. These calculations were performed during 1930-1931, but were first published only in 1937 in the form of an article in the collection Raketnaya tekhnika (Rocket Technology) No. 5, under the title "Thermal Calculation of a Liquid-Propellent Rocket Engine."

EXPERIMENTAL INVESTIGATIONS OF THE OPERATING PARAMETERS AND STRUCTURAL ELEMENTS OF A REACTION ENGINE ON THE LABORATORY MODEL

Occupied with the development of methods for engineering calculation of the operating processes and structural elements of LPRE, Tsander became convinced that it was impossible to give a satisfactory answer to many problems without obtaining experimental data lacking in the related sciences and technology. This involved propellent mixture formation in the chamber, combustion processes, discharge, heat exchange, etc. Thus arose the necessity of producing a laboratory model to experimentally verify the initial assumptions. The production of LPRE models thus assumed great importance in formulating and mastering experimental techniques.

The result was the production of the reaction engine OR-1. Without dwelling on a description of the OR-1 device, which is covered in the technical literature, we will note only the characteristics and role of this engine in design developments on LPRE. Tsander prepared calculations for the OR-1 according to his original technique for

+In the 1930s Eugen Sänger pursued a similar line of research in Germany, as he sought to create a "space transporter." See Irene Sänger-Bredt, "The Silver Bird Story: A Memoir," in this volume--Ed.

determining the parameters of LPRE. Liquid oxygen in mixture with liquid air served as the oxidizer. It is natural that the first tests of the engine began with the simplest version, i.e., with ordinary compressed air, with consideration of its gradual enrichment with oxygen, concluding with pure oxygen.

Experimental results obtained in tests of the OR-1, carried out with gasoline and compressed air, verified the calculation techniques, and gave Tsander the basis for continuing to design LPRE with the use of liquid oxygen and gasoline as propellants. The OR-1 engine permitted selecting the design solutions for the LPRE chamber. In this respect, the OR-1 should be considered a prototype of the OR-2 oxygen LPRE also produced by Tsander.

In evaluating this stage of Tsander's experimental work on the OR-1 laboratory model, one can conclude that it marked the production in the USSR of the first operating model of a rocket engine operating with liquid fuel and a gaseous oxidizer, and significantly aided the systematic development of works in producing oxygen LPRE and rocket vehicles at GIRD.

DEVELOPMENT OF THE GASOLINE-OXYGEN LPRE OR-2 FOR THE PILOTED VEHICLE (ROCKET PLANE) RP-1

One of the problems posed by this new techn[illegible] the USSR was the development of a suitable aviation LPRE. In order to provide [illegible] high a specific impulse as possible, and taking into account the promise of cryogenic fuels, Tsander selected liquid oxygen and gasoline as propellants for the OR-2 engine. In the long-range plan of LPRE development, he still contemplated using metal to supplement the propellants, and also proposed using the so-called "converging and diverging cone," in which the thermal action and acceleration of the gas flow was accomplished. However, taking into account the necessity of developing the OR-2 engine in a short time and providing for its high operational quality, Tsander refrained from applying metal additives and the "converging and diverging cone" at this first stage of work.

On the basis of preliminary calculations, he selected 300 sec as the engine operation time, sufficient for valid testing of the engine in flight, a thrust of 50 kg, sufficient for accomplishing flight, and a chamber pressure of 6-8 kg/cm^2. In such a pressure regime with a sufficiently high specific impulse, the heat flow from the gases to the chamber wall, as determined by Tsander's calculations, would have relatively small values, and reliable cooling of the combustion chamber could be successfully provided.

It is important to note that Tsander accomplished the development of LPRE in the first stage of work. The complex engine plant included all the systems and devices necessary for operating the LPRE in flight on the piloted vehicle—the combustion chamber, the fuel supply system, the launch assembly, and the ignition, operating mode, and cut-off controls. We will also note briefly some of the structural characteristics of the developed OR-2 engine. Tsander gave great consideration to the solution of the problems of propellant mixing. Taking into account the properties of gasoline combustion, he designed the structure of the chamber so that individual jets of gasoline, delivered to the chamber toward the nozzle along the chamber axis, were broken up into fine particles by the gaseous oxygen entering the OR-2 combustion chamber at its upper part radially through slots in the chamber wall. The fine drops of gasoline mixed well and burned with the proper completeness in the medium of gaseous oxygen.

Tsander considered the creation of a reliable chamber and nozzle cooling system as an important problem in producing LPRE. His calculations showed that liquid oxygen had better characteristics than gasoline as a cooling liquid. Moreover, the liquid oxygen evaporates in cooling the chamber walls, improving the mixing, which was just discussed.

Thrust regulation was first provided in the design of the OR-2 engine. The "nozzle valve" was developed for this purpose. Depending on the position of the control lever, various numbers of radially positioned holes were gradually covered in the inner cavity of the valve. Each fixed position of the control lever corresponded to a specified thrust developed by the engine. In designing the engine, the possibility of multiple firing of the engine was considered and provided for with the application of a high-voltage spark plug as the ignition source.

Tsander also accounted for the technological possibilities of production; as a result, the entire engine assembly was fabricated successfully and made ready for tests. The design of the OR-2 allowed for disassembly, and individual components and parts could be replaced or repaired during final adjustment and operation. Tsander and his students developed a flight model that assisted placement of the assemblies of the engine plant in the RP-1 rocket plane.

The firing tests of the OR-2 were carried out without F. A. Tsander, who was in the hospital in Kislovodsk during the test days. The tests occurred on March 18, March 21, March 26, and April 28, 1933. These were the tests of the first engine installation of LPRE produced at GIRD in a form suitable for mounting in a flying vehicle. Of course, the first tests did not achieve the expected satisfactory results. There were chamber burnouts, explosive combustion processes with firing, etc. Nevertheless, the results of the experimental data verified the possibility of implementing LPRE for piloted vehicles with high-caloric fuel. To increase the reliability of operation of the engine, improve its operational qualities, and reduce the time for preparing the engine for test, it was necessary to carry out laborious final adjustments and search for and select the most rational solutions with partial improvement of the structural elements of the engine.

This improvement, accomplished by Tsander's students A. I. Polyarny, the authors of this report, and other colleagues at GIRD, mainly involved realizing the following measures. First, to decrease the temperature of the gases in the chamber, it was decided to replace the gasoline with a highly concentrated solution of ethyl alcohol, which had been specified by Tsander in case difficulties were encountered with gasoline. Second, to improve the heat-shielding of the combustion chamber and nozzle, it was decided to protect the inner walls of the chamber and nozzle with a refractory heat-insulation layer. Coatings based on magnesium oxide were used for the nozzle, and aluminum oxide for the chamber. This permitted simplifying the design of the combustion chamber and fuel supply system.

The new version of the engine was identified as 02, and was finally prepared at the Jet Propulsion Research Institute (RNII) during 1934-1935. The firing tests, operating with liquid oxygen and 92% ethyl alcohol, obtained a combustion chamber pressure of 11 kg/cm^2, a thrust of 100 kg, a specific impulse on the order of 200 sec, and a firing duration of 60 sec. In 1936 the 02 engine was applied in flight tests of the 206 winged rocket designed by S. P. Korolev. Installation of the original OR-2 engine on the RP-1 rocket plane was not accomplished because the airframe was used for other purposes as the light airplane BICh-1.

DEVELOPMENT OF THE 10 ENGINE FOR THE GIRD-10 ROCKET

The second engine developed by Tsander was intended for the unguided liquid-propellent rocket GIRD-10, produced in 1932-1933 at GIRD for solving a number of scientific research problems. It differed from the GIRD-09 rocket developed during this same period in that both propellant components were stored in the GIRD-10 rocket in liquid form. Thus, the GIRD-10 rocket was the first domestic rocket that operated with LPRE. Numerous calculations carried out by Tsander, and particularly his students, preceded the design of this engine. In the initial version of the 10 engine, it was proposed to use liquid oxygen, gasoline, and molten or powdered metal as a fuel additive. However, in anticipation of technical and technological difficulties, this version was rejected.

After further calculation and design searches, the development of LPRE for the GIRD-10 rocket was accomplished with the application of liquid oxygen and ethyl alcohol. This engine, given the index 0-10, as well as the OR-2 engine, was initially designed by Tsander in the form of a complex engine plant coordinated with the parameters and features of the rocket itself. Tsander later participated in its development. The design of the entire engine plant was preceded by thorough hydraulic, gas-dynamic, and structural calculations, with consideration given to the production possibilities available at GIRD. We will briefly note some properties of this LPRE design.

The combustion chamber was all metal and pear-shaped, with a precombustion chamber and external liquid oxygen flow cooling. The absence of heat-insulation refractory coatings permitted producing a chamber of very low weight, which was very important since the chamber was intended for testing on a rocket under flight conditions. The combination of external liquid oxygen flow cooling with its partial evaporation in the cooling channel, and the presence of the precombustion chamber, ensured good mixing of the propellants and complete combustion in the chamber. In this case, the solution of this set of problems can be considered identical in the 0-10 and OR-2 engines.

To sum up the test operation of the 0-10 engine carried out in 1933 without Tsander, the following data were obtained: propellants—liquid oxygen and 85% ethyl alcohol, chamber pressure—10kg/cm^2, thrust—65-70 kg, specific impulse—175 sec. The duration of continuous operation was 15-20 sec. Ignition of the engine was accomplished with a spark plug. An expulsion system from a compressed air accumulator fed propellants to the engine combustion chamber. The mounting selected for the engine plant in the rocket was so successful that it obtained practical application in later designs, and its basic features are preserved to the present day.

The first test flight of the GIRD-10 rocket occurred on November 25, 1933, near Moscow. The entire engine assembly functioned normally during this test; the engine developed a thrust of 70 kg, and the rocket was successfully launched. During the flight, however, because of mechanical malfunctions in the combustion chamber, the rocket changed its direction of flight and landed with the engine still running.

The flight test of the first Soviet LPRE verified the promise of the scientific and technical direction developed at GIRD, and aided in accelerating the development of subsequent rocket designs in the USSR. Fridrikh Arturovich has characterized F. A. Tsander in the area of LPRE as a prominent theoretical scientist and talented engineer, distinguished by exceptional energy and single-mindedness in the realization of his ideas. His calculations, design, and experimental work on LPRE and rockets at the initial stage of development of rocket technology in the USSR show that he created his own school in the theory and design of reaction engines. Besides his engineering and theoretical developments, Tsander fashioned from a number of his students a large group of specialists who worked successfully in the following years in the area of rocket design in industry, in scientific laboratories, and in educational institutions.